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Innovative Co-Created Household Waste Management Practices and their Impact on Typhoid Reduction: Endline Evidence from Goma, North Kivu, DR Congo

Bahati Cimanuka Emmanuel[1]

[1]PhD Researcher in Community Health and Development

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Abstract: Typhoid fever remains a major public health challenge in rapidly urbanising and resource-constrained settings, where inadequate sanitation and poor waste management facilitate disease transmission. This study assessed the impact of innovative co-created household waste management practices on reducing typhoid fever in Goma, North Kivu, Democratic Republic of Congo. A cross-sectional comparative design was employed, involving 521 households (260 intervention and 261 control) selected through multistage sampling technique. The intervention, co-developed with community members, promoted practices such as waste separation, composting, organised evacuation, and improved waste storage. Data were collected using semi-structured questionnaires, validated through health facility records and observational checklists, and analysed using descriptive statistics and chi-square tests.

The findings indicate that the intervention significantly improved the adoption of sustainable waste management practices and contributed to a substantial reduction in typhoid fever prevalence. In the intervention group, prevalence declined from 43.8% at baseline to 12.7% at endline (−31.1%), compared to a smaller reduction in the control group (−8.8%). Practices such as waste separation, organised evacuation, and controlled incineration were associated with decreased disease risk, while improper composting was linked to increased prevalence, highlighting potential health risks when not properly managed Overall, the study demonstrates that community-based, participatory waste management interventions can effectively reduce typhoid transmission by improving environmental sanitation. However, the findings also emphasise the importance of proper technical guidance and monitoring to ensure safe implementation of environmentally friendly practices. These results underscore the need for integrated approaches that combine behavioural change, infrastructure development, and community engagement to enhance public health outcomes and support sustainable urban development.

Keywords: *Innovative, Co-Created, Household Waste Management, Practices, Impact, Typhoid Reduction, Goma.*

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I. INTRODUCTION

Typhoid fever remains a major public health challenge in sub-Saharan Africa, particularly in urban settings where rapid population growth, inadequate sanitation, and poor waste management converge to exacerbate transmission risks (Id *et al*., 2024). The disease, caused by *Salmonella enterica* serovar Typhi, is primarily spread through the fecal–oral route, making household-level water, sanitation, and hygiene (WASH) practices critical determinants of infection (Kim *et al*., 2023). Globally, an estimated 11–20 million cases of typhoid fever occur annually, with significant morbidity and mortality concentrated in low- and middle-income countries (Shruti Murthy *et al*., 2025).

In the Democratic Republic of Congo (DRC), typhoid fever is endemic, with recurrent outbreaks linked to fragile health systems, limited access to clean water, and insufficient waste management infrastructure (WHO, 2024a; Steckman, 2021). Goma, the capital of North Kivu Province, exemplifies these challenges. The city's rapid urbanisation, compounded by displacement due to conflict, has strained municipal services and left many households reliant on unsafe waste disposal practices (Mukuku *et al*., 2025). Studies in similar contexts have shown that poor waste management, such as indiscriminate dumping, open incineration, and lack of composting, creates breeding grounds for pathogens and vectors, thereby increasing the risk of typhoid transmission (Okesanya *et al*., 2024; Kariuki et al., 2020).

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Innovative, community-driven approaches to waste management have emerged as promising interventions to reduce disease burden. Evidence suggests that co-created strategies, where households, local leaders, and researchers jointly design and implement waste management practices, enhance adoption, sustainability, and health outcomes (Gritzas, 2024). Practices such as waste separation, composting, and organised evacuation not only improve environmental hygiene but also directly reduce exposure to contaminated materials, thereby lowering typhoid incidence (WHO, 2023b). Conversely, reliance on unsafe methods like uncontrolled incineration has been associated with persistent health risks (Bottini *et al*., 2025)

This study assesses the *effect of a co-created household waste management intervention on reducing typhoid fever among households in Goma***.** By comparing intervention and control groups at endline, and analysing adoption patterns across age, gender, marital status, and education, the research provides robust evidence on how participatory waste management practices can mitigate typhoid transmission (Okesanya *et al*., 2024). The findings contribute to the broader discourse on WASH innovations in resource-constrained urban settings and highlight the potential of community-led environmental health strategies to advance Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 11 (Sustainable Cities and Communities) (IFRC, 2024).

II. METHODOLOGY

➢ *Study Design Approach and Setting*

This study employed a cross-sectional comparative design to assess Innovative Co-Created Household Waste Management Practices and their impact on Typhoid Reduction: Endline evidence from Goma, North Kivu, DR Congo (Assemu *et al.,* 2020). The design enabled assessment of associations between household waste management practices and reported typhoid fever incidence. Goma was selected due to its rapid urbanisation, fragile municipal services, and recurrent typhoid outbreaks linked to poor sanitation and waste disposal practices (WHO, 2025; Mbeva *et al.*, 2020). The intervention was co-created with households, local leaders, and researchers to ensure contextual relevance and sustainability, consistent with participatory approaches in WASH programming (WASH Cluster, 2024).

➢ *Study Population and Sampling*

The study population comprised households residing in Goma Town, specifically in the Ndosho district of Karisimbi Commune and the Kyeshero district of Goma Commune. Eligible households included at least one adult respondent (≥18 years) who was knowledgeable about household waste management practices and past typhoid fever episodes among family members (Ssemugabo *et al.,* 2025). Intervention households, drawn from Ndosho district, had participated in co-created waste management practices such as composting, waste separation, and organised evacuation, while control households from Kyeshero district continued with conventional practices. In total, 521 households were sampled, comprising 260 intervention households and 261 control households, selected using a multistage sampling technique (Kim *et al*., 2023). The sample size was determined using Sakpal's formula**,** ensuring adequate statistical power for comparative analysis.

To minimise sampling bias in this heterogeneous urban population, a stratified random sampling approach was employed, ensuring representation across key socio-demographic variables, including age, gender, marital status, and education level of household heads (Shahid *et al*., 2025). Inclusion criteria required households to have resided in Goma for at least six months and to provide informed consent to participate in the study.

➢ *Data Collection Methods*

Data were collected using semi-structured questionnaires administered to household heads, a common tool in community health research (Saunders-Russell, 2016). The questionnaires captured demographic characteristics, adoption of specific waste management practices, and self-reported typhoid fever cases. To enhance validity, household reports were verified against health facility records in selected clinics, following best practices for triangulation in epidemiological studies (Hasselgreen *et al*., 2016). Field enumerators were trained to ensure consistency in data collection and minimize interviewer bias. Observational checklists were also used to validate reported practices (e.g., presence of compost pits, storage bags, incineration sites), consistent with WASH monitoring frameworks (WHO&UNICEF, 2023).

➢ *Data Analysis*

Data were entered and cleaned using SPSS (version 27)**.** Descriptive statistics summarized household characteristics and waste management practices. Associations between practices and typhoid fever incidence were tested using chi-square tests**,** appropriate for categorical data (Agresti, 2018 cited by Miyoba M. Habanji, 2024). Odds ratios (OR) with 95% confidence intervals (CI) were computed to estimate the strength of associations. Statistical significance was set at $p < 0.05$**.** Comparative analyses were conducted between intervention and control groups, and stratified analyses examined adoption patterns across age, gender, marital status, and education, consistent with epidemiological reporting standards (Strobe Group, 2024).

➢ *Ethical Considerations*

Ethical approval was obtained from the Great Lakes University of Kisumu Institutional Review Board and local health authorities in Goma. Consent was obtained from all participants to take part in this study. Their participation was voluntary, confidentiality was guaranteed, and no personally identifiable data was recorded. Participants who reported typhoid-like symptoms were advised to seek appropriate care at health facilities.

III. RESULTS

➢ *Description of Endline (Intervention vs Control Groups)*

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Table 1 Distribution of Waste Management Practices and Age of the Respondents in the Endline

Types of Waste Management Practices	Intervention Group Yes (n)	Intervention Group Proportion (%)	Intervention Group No (n)	Intervention Group Proportion (%)	P-value	Control Group Yes (n)	Control Group Proportion (%)	Control Group No (n)	Control Group Proportion (%)	P-value
Waste separation	172	66.2%	88	33.8%	0.033	149	57.1%	112	42.9%	0.038
Waste composting	205	78.8%	55	21.2%	<0.001	81	31.0%	180	69.0%	<0.001
Waste incineration	28	10.8%	232	89.2%	<0.001	160	61.3%	101	38.7%	<0.001
Storage in bags	105	40.4%	155	59.6%	0.619	111	42.5%	150	57.5%	0.657
Evacuation	260	100.0%	0	0.0%	<0.001	124	47.5%	137	52.5%	<0.001

- Note. Frequencies (n) and proportions (%) are presented separately for Yes and No responses in both intervention and control groups. P-values represent the significance of group differences in waste management practices.

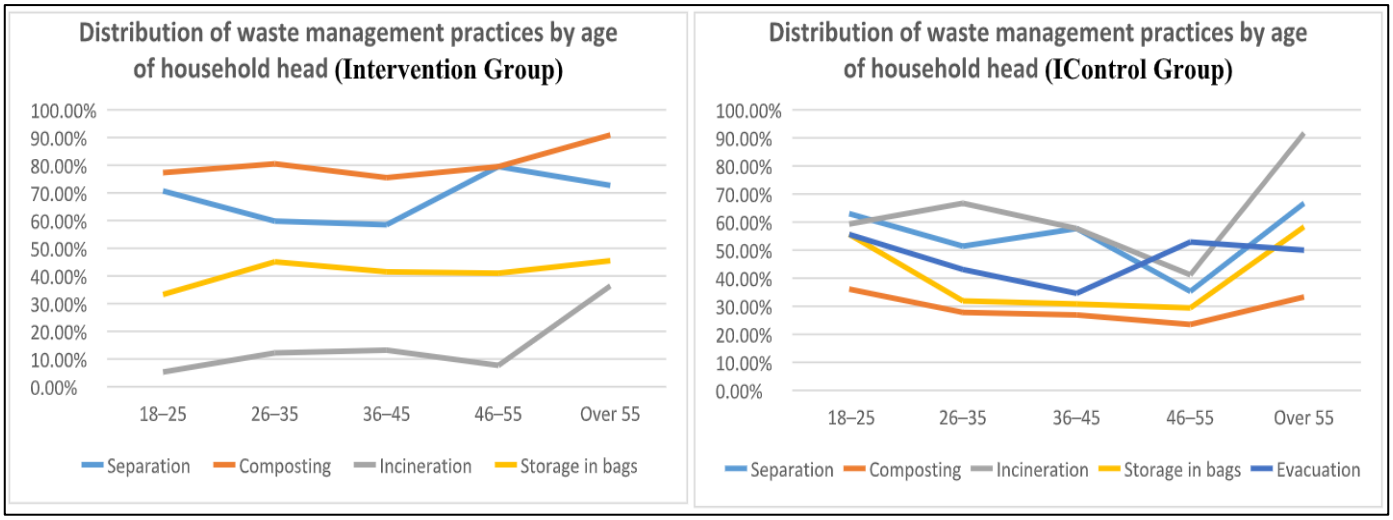

Fig 1 Adoption of Waste Management Practices by Age in the Intervention and Control Groups.

The most commonly adopted practices, Intervention Group, Evacuation (100.0 %) and composting (78.8%) are the most positively impacted practices, both with strong statistical significance ($p < 0.001$). Incineration shows a sharp contrast: *minimally used* in the intervention group (10.8%) but *widely practiced* in the control group (61.3%), statically significant in both groups (p= 0.001). Storage in bags remains marginal (40.4% for intervention and 42.5% for control) and statistically insignificant in both groups (respectively p= 0.619 vs p=0.657). Waste separation is moderately adopted across both groups, with slightly higher uptake in the intervention group (66.2% vs 57.1%), with (p=0.033 in intervention, vs p=0.038 in control) both statically significant. (See table 1).

Age-based utilisation of solid waste management practices, in the intervention group, household heads aged Over 55 consistently lead in the adoption of promoted solid waste management practices. They demonstrate the highest overall engagement, particularly in composting, adoption peaks at 90.9%, the highest across all age categories. Waste Separation, reaches 72.7%, showing a recovery and peak after mid-age fluctuations.

Incineration, despite being discouraged, this age group records the highest uptake within the intervention group. Storage in Bags, shows a slight increase, though remains marginal overall. In the control group, households headed by individuals Over 55 also emerge as the most consistent adopters, especially in Separation (66.7%); Incineration (91.7%) and Storage in Bags (58.3%). Meanwhile, younger respondents (18–25) show strong engagement with composting (63.0%) and Evacuation: 55.6%. Middle-aged groups (26–45) display greater variability and generally lower adoption rates, with incineration being the most prominent practice (66.7% in the 26–35 age group). (See figure 1).

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Table 2 Distribution of Waste Management Practices and Gender of the Respondents in Endline

Waste Management Practice	Gender	Intervention Group Yes (n)	Intervention Group Proportion (%)	Intervention Group No (n)	Intervention Group Proportion (%)	P-value	Control Group Yes (n)	Control Group Proportion (%)	Control Group No (n)	Control Group Proportion (%)	P-value
Waste separation - Male	Male	58	63.0%	34	37.0%	0.033	57	58.2%	41	41.8%	0.038
Waste separation - Female	Female	114	67.9%	54	32.1%		92	56.4%	71	43.6%	
Waste composting - Male	Male	69	75.0%	23	25.0%	<0.001	27	27.6%	71	72.4%	<0.001
Waste composting - Female	Female	136	81.0%	32	19.0%		54	33.1%	109	66.9%	
Waste incineration - Male	Male	9	9.8%	83	90.2%	<0.001	54	55.1%	44	44.9%	<0.001
Waste incineration - Female	Female	19	11.3%	149	88.7%		106	65.0%	57	35.0%	
Storage in bags - Male	Male	47	51.1%	45	48.9%	0.619	35	35.7%	63	64.3%	0.657
Storage in bags - Female	Female	58	34.5%	110	65.5%		76	46.6%	87	53.4%	
Evacuation - Male	Male	92	100.0%	0	0.0%	<0.001	39	39.8%	59	60.2%	<0.001
Evacuation - Female	Female	168	100.0%	0	0.0%		85	52.1%	78	47.9%	

- Note. Frequencies (n) and proportions (%) are presented separately for Yes and No responses by gender in both intervention and control groups. P-values represent the significance of group differences in waste management practices.

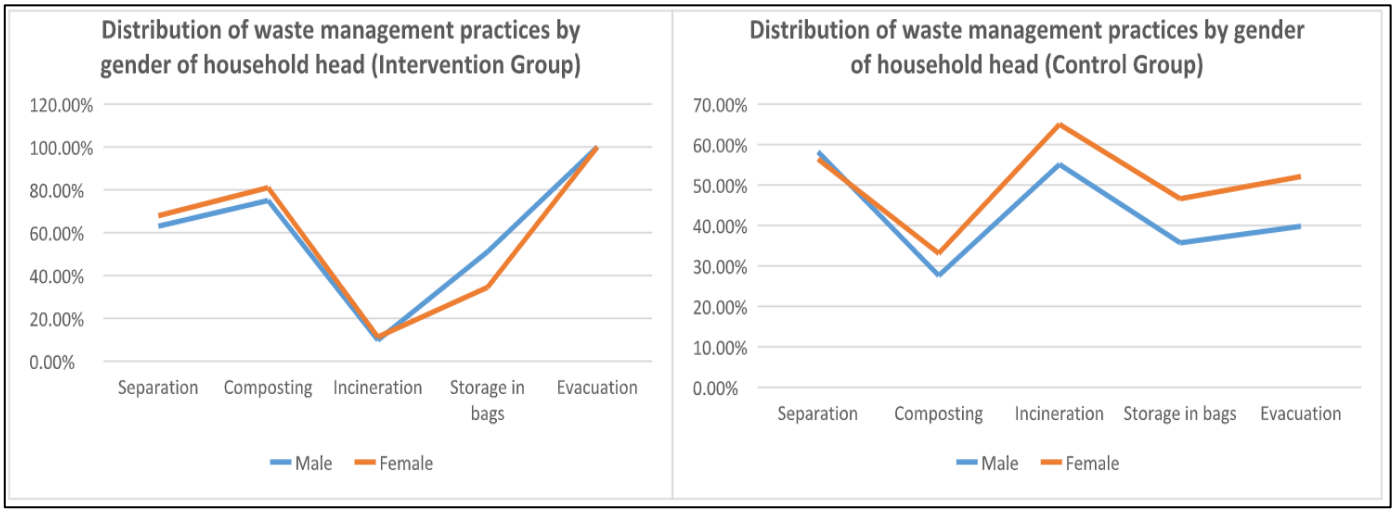

Fig 2 Adoption of Waste Management Practices by Gender in the Intervention and Control Groups.

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Based on the data from the intervention group, the most commonly adopted waste management practices across gender categories are: Evacuation, universally adopted by both male (100.0%) and female (100.0%) respondents, statistically significant ($p < 0.001$).

Composting, high uptake among females (81.0%) and males (75.0%), females show slightly higher adoption, strong statistical significance ($p < 0.001$). Waste Separation, moderately adopted by females (67.9%) and males (63.0%), females lead slightly, statistically significant for males ($p = 0.033$). Less adopted or marginal practices include, Incineration, low adoption among females (11.3%) and males (9.8%), despite low uptake, statistically significant ($p < 0.001$). Storage in Bags, higher among males (51.1%) than females (34.5%), statistically insignificant ($p = 0.619$).

In Control Group, among female respondents, the most commonly adopted practices are: Incineration (65.0%) adoption, highest across all practices and genders, statistically significant ($p < 0.001$). Waste Separation (56.4%) adoption, slightly below male rate (58.2%), still among the top practices. Evacuation (52.1%) adoption, higher than male counterparts (39.8%), statistically significant ($p < 0.001$).

Marginal practices across both genders include: Composting, for Females (33.1%) and Males (27.6%), statistically significant ($p < 0.001$), but low overall uptake. Storage in Bags for Females (46.6%) and Males (35.7%), moderate adoption, but statistically insignificant ($p = 0.657$). (See table 2).

In terms of utilisation by gender within the intervention group, female respondents consistently lead in the most widely adopted waste management practices, notably Separation (67.90%) and Composting (81.00%). They also show higher engagement in Incineration (11.30%), despite its lower overall adoption. Male respondents lead only in Storage in bags (51.10%), where female participation is comparatively lower (34.50%). Evacuation is universally practiced by both genders, with a 100% utilisation rate. In the control group, female respondents again demonstrate leadership across most practices, particularly in Incineration (65.00%), Storage in bags (46.60%), and Evacuation (52.10%), all among the more commonly adopted methods. While males slightly outperform females in Separation (58.20% vs. 56.40%), the overall trend indicates a stronger female presence in household waste management activities. *(See figure 2).*

Table 3 Distribution of Waste Management Practices and Marital Status of the Respondents in Endline

Practice	**Marital Status**	**Intervention Group Yes (n)**	**Intervention Group Yes (%)**	**Intervention Group No (n)**	**Intervention Group No (%)**	**p-value**	**Control Group Yes (n)**	**Control Group Yes (%)**	**Control Group No (n)**	**Control Group No (%)**	**p-value**
Separation	Single	54	76.1%	17	23.9%	0.042	44	60.3%	29	39.7%	0.050
	Married	111	62.7%	66	37.3%	0.216	99	56.3%	77	43.7%	0.234
	Widowed	3	60.0%	2	40.0%	1.000	3	60.0%	2	40.0%	0.738
	Divorced	4	57.1%	3	42.9%	0.593	3	42.9%	4	57.1%	0.500
Composting	Single	54	76.1%	17	23.9%	<0.001	22	30.1%	51	69.9%	<0.001
	Married	140	79.1%	37	20.9%	<0.001	56	31.8%	120	68.2%	<0.001
	Widowed	5	100.0%	0	0.0%	0.038	2	40.0%	3	60.0%	0.083
	Divorced	6	85.7%	1	14.3%	0.008	1	14.3%	6	85.7%	0.029
Incineration	Single	3	4.2%	68	95.8%	<0.001	46	63.0%	27	37.0%	<0.001
	Married	24	13.6%	153	86.4%	<0.001	108	61.4%	68	38.6%	<0.001
	Widowed	0	0.0%	5	100.0%	0.114	2	40.0%	3	60.0%	0.070
	Divorced	1	14.3%	6	85.7%	0.094	4	57.1%	3	42.9%	0.133
Storage	Single	25	35.2%	46	64.8%	0.018	40	54.8%	33	45.2%	0.020
	Married	74	41.8%	103	58.2%	0.204	62	35.2%	114	64.8%	0.246

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	Widowed	3	60.0%	2	40.0%	0.114	5	100.0%	0	0.0%	0.070
	Divorced	3	42.9%	4	57.1%	0.593	4	57.1%	3	42.9%	0.500
Evacuation	Single	71	100.0%	0	0.0%	<0.001	43	58.9%	30	41.1%	<0.001
	Married	177	100.0%	0	0.0%	<0.001	75	42.6%	101	57.4%	<0.001
	Widowed	5	100.0%	0	0.0%	0.114	3	60.0%	2	40.0%	0.070
	Divorced	7	100.0%	0	0.0%	0.018	3	42.9%	4	57.1%	0.035

- Note. Frequencies (n) and proportions (%) show the distribution of waste management practices according to marital status in both intervention and control groups at endline. p-values represent the significance of differences between groups.

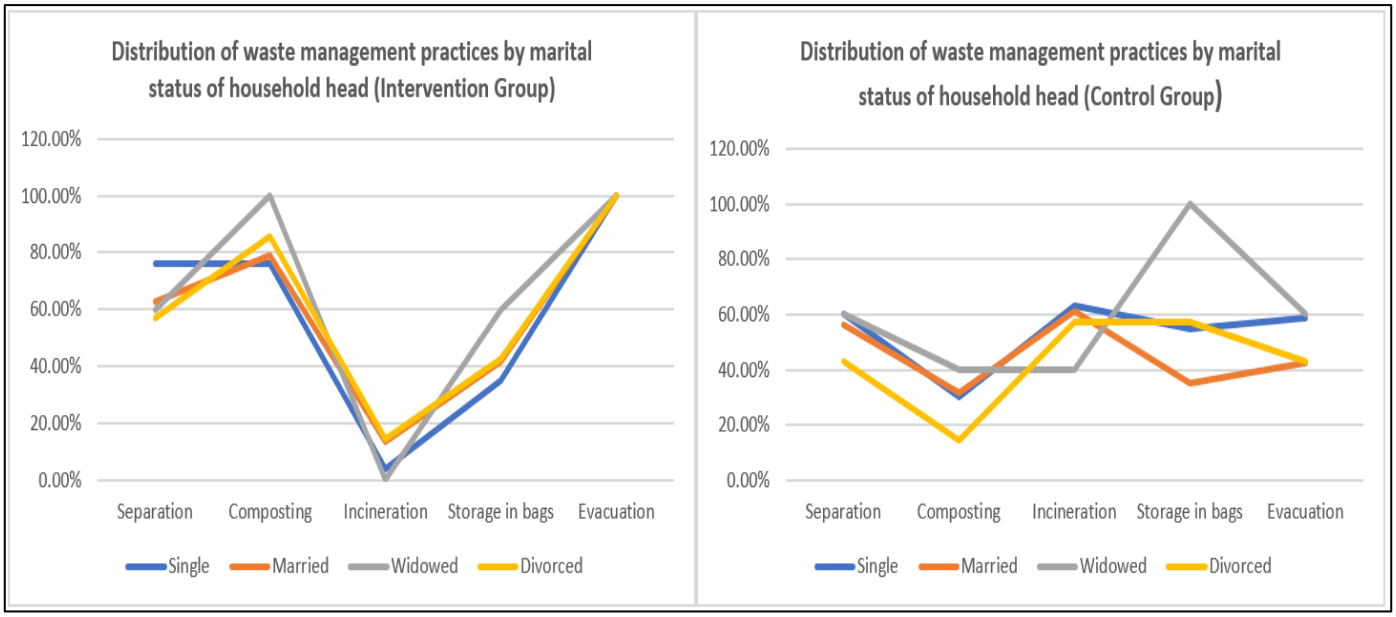

Fig 3 Adoption of Waste Management Practices by Marital Status in the Intervention and Control Groups.

Across marital status categories, in the intervention group, Composting stands out as the most widely adopted and statistically significant waste management practice. Uptake is highest among widowed respondents (100%, $p = 0.038$), followed by divorced (85.7%, $p = 0.008$), and married individuals (79.1%, $p < 0.001$). Separation is also notably practiced among single respondents (76.1%, $p = 0.042$), but Composting matches this rate and shows stronger overall significance ($p < 0.001$). In contrast, Incineration and Storage are less commonly adopted across all marital categories, with lower proportions, such as 4.2% for singles and 0.0% for widowed, and less consistent statistical relevance ($p < 0.001$ and $p = 0.114$, respectively). In the control group, Incineration emerges as the most consistently adopted practice across marital status categories, particularly among single (63.0%) and married (61.4%) respondents, both with strong statistical significance ($p < 0.001$). Evacuation (58.9%, $p < 0.001$) and Separation (60.3%, $p = 0.050$) also show notable adoption among singles. Storage is exceptionally high among widowed respondents (100%, $p = 0.070$), though not statistically significant. Composting, on the other hand, records the lowest adoption rates across all categories, from widowed (40.0%) to divorced (14.3%), with significant p-values ($p = 0.083$ and $p = 0.029$), indicating limited uptake. (See table 3).

In term of utilisation of waste management practices by Marital Status, in the intervention group, widowed respondents lead in Composting (100.00%) and Storage in bags (60.00%), demonstrating perfect or high adoption rates. Single respondents show the highest uptake in Separation (76.10%), one of the most widely adopted practices. Divorced respondents lead in Incineration (14.30%), although this method remains less commonly practiced overall. Evacuation is universally adopted across all marital status categories, with a 100.00% utilisation rate. In the control group, widowed respondents again lead in several practices, including Storage in bags (100.00%), Evacuation (60.00%), and Composting (40.00%). Single respondents lead in Incineration (63.00%) and tie with widowed respondents in Separation, both at 60.00%. Married and divorced respondents do not lead in any of the most widely adopted practices. (See figure 3).

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Table 4 Distribution of Waste Management Practices and Education Level of the Respondents in Endline

Waste Management Practice	Education Level	Intervention Group Yes (n)	Intervention Group Yes (%)	Intervention Group No (n)	Intervention Group No (%)	p-value	Control Group Yes (n)	Control Group Yes (%)	Control Group No (n)	Control Group No (%)	p-value
Waste separation	Without education	32	80.0%	8	20.0%	0.013	11	45.8%	13	54.2%	0.013
	Primary School	24	80.0%	6	20.0%	0.087	14	58.3%	10	41.7%	0.087
	Secondary School	94	62.3%	57	37.7%	0.276	71	56.3%	55	43.7%	0.276
	Professional training	7	87.5%	1	12.5%	0.074	11	55.0%	9	45.0%	0.074
	Bachelor	15	48.4%	16	51.6%	0.148	42	63.6%	24	36.4%	0.148
	Master	0	0.0%	1	100.0%	1.000	0	0.0%	1	100.0%	1.000
Waste composting	Without education	36	90.0%	4	10.0%	<0.001	5	20.8%	19	79.2%	<0.001
	Primary School	26	86.7%	4	13.3%	<0.001	6	25.0%	18	75.0%	<0.001
	Secondary School	112	74.2%	39	25.8%	<0.001	42	33.3%	84	66.7%	<0.001
	Professional training	8	100.0%	0	0.0%	<0.001	6	30.0%	14	70.0%	<0.001
	Bachelor	23	74.2%	8	25.8%	<0.001	22	33.3%	44	66.7%	<0.001
	Master	0	0.0%	1	100.0%	1.000	0	0.0%	1	100.0%	1.000
Waste incineration	Without education	6	15.0%	34	85.0%	<0.001	16	66.7%	8	33.3%	<0.001
	Primary School	3	10.0%	27	90.0%	<0.001	17	70.8%	7	29.2%	<0.001
	Secondary School	17	11.3%	134	88.7%	<0.001	76	60.3%	50	39.7%	<0.001
	Professional training	2	25.0%	6	75.0%	0.005	12	60.0%	8	40.0%	0.005
	Bachelor	0	0.0%	31	100.0%	<0.001	38	57.6%	28	42.4%	<0.001
	Master	1	100.0%	0	0.0%	1.000	1	100.0%	0	0.0%	1.000
Storage in bags	Without education	6	15.0%	34	85.0%	0.003	11	45.8%	13	54.2%	0.003
	Primary School	8	26.7%	22	73.3%	0.094	9	37.5%	15	62.5%	0.094
	Secondary School	69	45.7%	82	54.3%	0.252	59	46.8%	67	53.2%	0.252
	Professional training	1	12.5%	7	87.5%	0.003	11	55.0%	9	45.0%	0.003

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	Bachelor	21	67.7%	10	32.3%	<0.001	21	31.8%	45	68.2%	<0.001
	Master	0	0.0%	1	100.0%	1.000	0	0.0%	1	100.0%	1.000
Evacuation	Without education	40	100.0%	0	0.0%	<0.001	13	54.2%	11	45.8%	<0.001
	Primary School	30	100.0%	0	0.0%	<0.001	11	45.8%	13	54.2%	<0.001
	Secondary School	151	100.0%	0	0.0%	<0.001	69	54.8%	57	45.2%	<0.001
	Professional training	8	100.0%	0	0.0%	<0.001	10	50.0%	10	50.0%	<0.001

- Note. Frequencies (n) and proportions (%) represent the distribution of waste management practices across different education levels for both intervention and control groups at endline. p-values indicate the level of statistical significance.

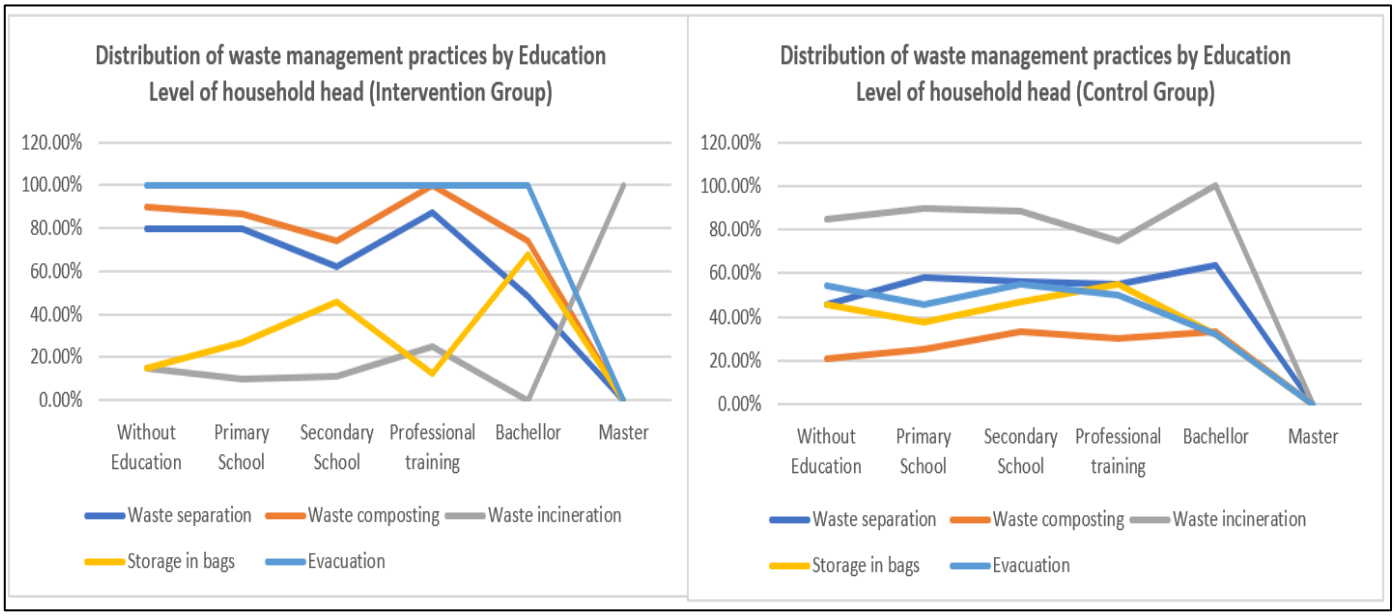

Fig 4 Adoption of Waste Management Practices by Education Level in the Intervention and Control Groups.

Across education levels in the intervention group, Evacuation is the most universally adopted practice across all education levels, with a 100% uptake and strong statistical significance ($p < 0.001$); Composting follows closely, with high adoption rates across all levels except Master's (0.0%), and consistently significant p-values. Separation is also widely practiced, especially among those without education and those with primary education (both at 80.0%), though with slightly weaker significance. Storage in bags shows notable uptake among Bachelor-level respondents (67.7%, $p < 0.001$), while other groups show lower engagement. Incineration is generally less adopted, except for the Master's group, which shows 100% uptake, but this result is based on a single respondent and lacks statistical weight. In control group, Incineration is the most consistently adopted and statistically significant (p <0.001practice across all education levels, with the highest uptake among primary school (70.8%) and without education (66.7%) groups. Evacuation shows moderate adoption across most levels, particularly among secondary school (54.8%) and without education (54.2%) respondents. Those with professional training (55.0%) and secondary education (46.8%) notably practice storage in bags, though significance varies. Separation is moderately adopted, with Bachelor-level respondents showing the highest rate (63.6%), though without strong statistical significance (0.148 / <0.001). Composting has the lowest adoption rates across all education levels, ranging from 20.8%for without education to 33.3% for secondary school, despite statistically significant p-values indicating low uptake. (See table 4).

In terms of utilisation by age within the intervention group, Professional training emerges as the most consistent leader, showing high adoption rates in waste separation (87.5%), waste composting (100%) and Evacuation (100%, tied with other groups). Master's level respondents demonstrate specialised engagement, with full participation in waste incineration (100%) but no involvement in other practices. Bachelor's level leads in storage using bags (67.7%), but shows lower adoption in composting and

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separation. Respondents Without Formal Education display unexpectedly high engagement in Composting (90%) and Separation (80%). In Control Group, Bachelor's level respondents lead in Waste separation (63.6%), Waste incineration (100%) and Composting (33.3%, tied with others). Secondary school respondents show strong performance in Evacuation (54.8%), Composting (33.3%, tied) and waste separation (56.3%, second highest). Professional training shows leadership only in storage using bags (55%), with limited adoption of other practices. Master's level respondents report zero participation across all practices, indicating minimal engagement. (See figure 4).

Table 5 Distribution of Waste Management Practices and Religion of the Respondents in Endline

Practice	Religion	Yes (n)	Yes (%)	No (n)	No (%)	p-value	Yes (n)	Yes (%)	No (n)	No (%)	p-value
Waste separation	Catholic	60	68.2%	28	31.8%	0.041	57	59.4%	39	40.6%	0.048
	Protestant	52	64.2%	29	35.8%		57	60.0%	38	40.0%	
	Muslim	11	68.8%	5	31.2%		3	37.5%	5	62.5%	
	Adventist	18	60.0%	12	40.0%		12	48.0%	13	52.0%	
	Revival church	18	62.1%	11	37.9%		9	50.0%	9	50.0%	
	Other church	8	72.7%	3	27.3%		9	69.2%	4	30.8%	
	Without religion	5	100.0%	0	0.0%		2	33.3%	4	66.7%	
Waste composting	Catholic	67	76.1%	21	23.9%	<0.001	35	36.5%	61	63.5%	<0.001
	Protestant	67	82.7%	14	17.3%		28	29.5%	67	70.5%	
	Muslim	14	87.5%	2	12.5%		1	12.5%	7	87.5%	
	Adventist	19	63.3%	11	36.7%		7	28.0%	18	72.0%	
	Revival church	22	75.9%	7	24.1%		7	38.9%	11	61.1%	
	Other church	11	100.0%	0	0.0%		1	7.7%	12	92.3%	
	Without religion	5	100.0%	0	0.0%		2	33.3%	4	66.7%	
Waste incineration	Catholic	10	11.4%	78	88.6%	<0.001	60	62.5%	36	37.5%	<0.001
	Protestant	8	9.9%	73	90.1%		60	63.2%	35	36.8%	
	Muslim	0	0.0%	16	100.0%		4	50.0%	4	50.0%	
	Adventist	2	6.7%	28	93.3%		13	52.0%	12	48.0%	
	Revival church	3	10.3%	26	89.7%		12	57.1%	6	42.9%	
	Other church	4	36.4%	7	63.6%		8	61.5%	5	38.5%	
	Without religion	1	20.0%	4	80.0%		3	50.0%	3	50.0%	
Storage in bags	Catholic	34	38.6%	54	61.4%	0.619	44	45.8%	52	54.2%	0.657
	Protestant	31	38.3%	50	61.7%		40	42.1%	55	57.9%	
	Muslim	7	43.8%	9	56.2%		6	75.0%	2	25.0%	
	Adventist	12	40.0%	18	60.0%		9	36.0%	16	64.0%	
	Revival church	16	55.2%	13	44.8%		5	27.8%	13	72.2%	
	Other church	2	18.2%	9	81.8%		4	30.8%	9	69.2%	
	Without religion	3	60.0%	2	40.0%		3	50.0%	3	50.0%	
Evacuation	Catholic	88	100.0%	0	0.0%	<0.001	48	50.0%	48	50.0%	<0.001
	Protestant	81	100.0%	0	0.0%		44	46.3%	51	53.7%	
	Muslim	16	100.0%	0	0.0%		4	50.0%	4	50.0%	
	Adventist	30	100.0%	0	0.0%		13	52.0%	12	48.0%	

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	Revival church	29	100.0%	0	0.0%		7	38.9%	11	61.1%	
	Other church	11	100.0%	0	0.0%		7	53.8%	6	46.2%	
	Without religion	5	100.0%	0	0.0%		1	20.0%	5	80.0%	

- Note. This table presents the distribution of waste management practices by religion among respondents in the endline survey.

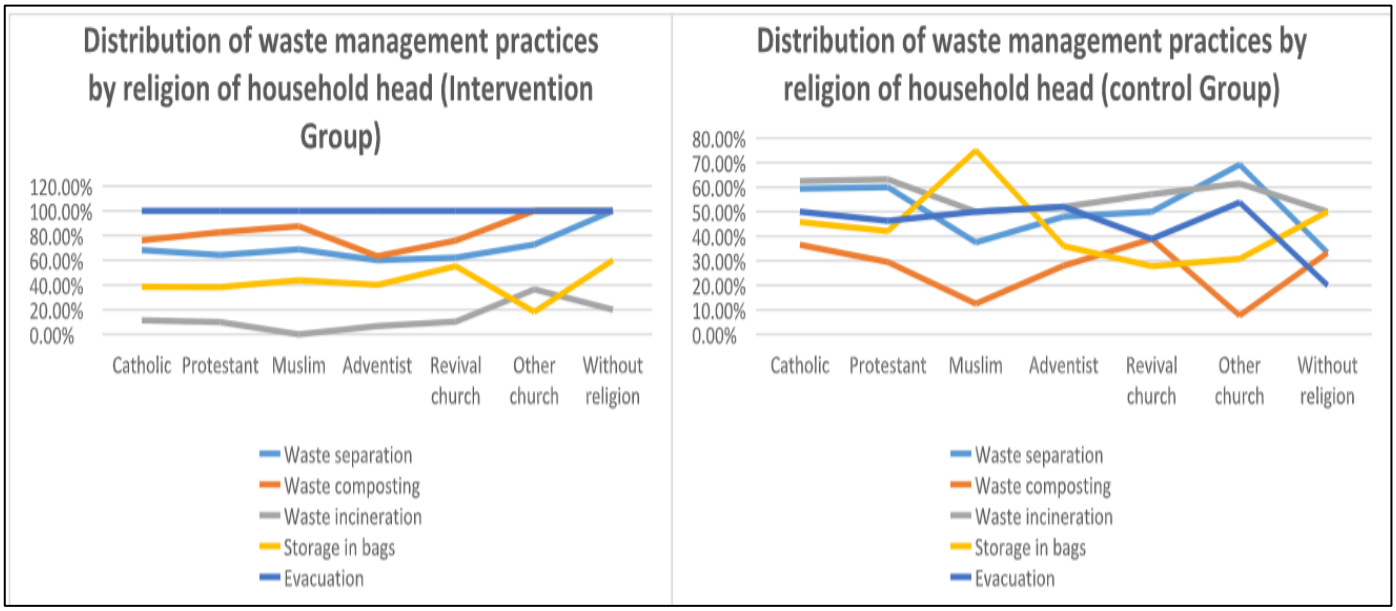

Fig 5 Adoption of Waste Management Practices by Religion in the Intervention and Control Groups.

Across religion status categories, in intervention Group, Evacuation and composting are the most widely adopted waste management practices across all religious categories. Evacuation is universally adopted, with 100% participation reported by all groups, including those without religious affiliation. This practice demonstrates the strongest consensus, supported by a statistically significant p-value (<0.001).

Religion appears to influence composting and separation behaviours, both showing significant variation across groups. Composting is highly adopted among Muslims (87.5%), Protestants (82.7%), Catholics (76.1%), Revival Church members (75.9%), and both Other Church and non-religious respondents (100%). The p-value (<0.001) confirms a meaningful difference in adoption rates by religion.

Waste separation also shows strong uptake among other church members (72.7%), Muslims (68.8%), Catholics (68.2%), and those without religion (100%), with a statistically significant p-value of 0.041. In contrast, incineration and storage in bags exhibit lower and more variable adoption. Storage in bags is most common among respondents without religion (60%), Revival Church members (55.2%), and Muslims (43.8%). However, overall adoption is moderate and not statistically significant (p = 0.619). Waste incineration shows generally low adoption across all groups, with the highest rates among other church members (36.4%) and non-religious respondents (20%). Most other groups report adoption rates below 12%, though the variation is statistically significant (p < 0.001).

In the Control Group, waste incineration is the most commonly adopted practice across religious categories. Protestants (63.2%), Catholics (62.5%), Other Church members (61.5%), Revival Church members (57.1%), Adventists (52.0%), Muslims, and non-religious respondents (50.0%) all show relatively high engagement, with significant variation (p < 0.001). Waste separation shows moderate adoption, particularly among Other Church members (69.2%), Protestants (60.0%), and Catholics (59.4%). Lower adoption is observed among Muslims (37.5%) and those without religion (33.3%), with a statistically significant p-value of 0.048, indicating religion may influence separation behaviour.

Other church members (53.8%), Adventists (52.0%), Muslims, and Catholics (50.0%) most commonly practice evacuation, while the lowest adoption is among non-religious respondents (20.0%). Despite moderate overall rates, the p-value (<0.001) suggests meaningful differences across religious groups. Storage in bags is most prevalent among Muslims (75.0%), followed by Catholics (45.8%) and Protestants (42.1%). The lowest adoption is seen among Revival church members (27.8%) and other church members (30.8%). However, this variation is not statistically significant (p = 0.657). Composting and evacuation are less consistently adopted in the control group, with notable variation by religion. Composting is highest among Revival

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church members (38.9%) and Catholics (36.5%), but very low among Other church members (7.7%) and Muslims (12.5%). The differences are statistically significant ($p < 0.001$), though overall adoption remains low. (See table 5).

In terms of utilisation by religion within the intervention group, respondents without religious affiliation consistently demonstrate the highest engagement across key practices, with full participation in evacuation, composting, and separation (100%), and leading in storage in bags (60%). Other church members also show strong involvement, particularly in composting (100%), separation (72.7%), and incineration (36.4%). protestant and muslim households rank prominently in composting (82.7% and 87.5%, respectively) and separation (64.2% and 68.8%), though their participation in other practices is comparatively lower.

In control group, protestants and catholics emerge as consistent adopters of incineration, separation, and evacuation, with protestants leading in incineration (63.2%) and catholics close behind (62.5%). other notable rates include other church (61.5%), revival church (57.1%), Adventists (52.0%), and both muslims and without religion respondents (50.0%). Other church respondents lead in separation and evacuation (69.2% and 53.8%, respectively), but show minimal engagement in composting (7.7%). Protestants (60.0%) and catholics (59.4%) also maintain strong participation in separation, while muslims (37.5%) and without religion (33.3%) report lower rates. in storage in bags, muslim households stand out with the highest adoption (75.0%), followed by without religion (50.0%) and catholics (45.8%). Other groups show moderate to low engagement, especially revival church (27.8%) and other church (30.8%).

For evacuation, other church leads (53.8%), with adventists (52.0%), catholics, and muslims (50.0%) showing moderate uptake. The lowest participation is among without religion respondents (20.0%). Composting is the least adopted practice overall. Revival church leads modestly (38.9%), followed by catholics (36.5%), while other church (7.7%) and muslims (12.5%) show minimal involvement. (See figure 5).

➢ *Waste Management Practices — Baseline vs Endline*

Table 6 Waste Management Practices — Baseline vs Endline

Waste Management Practice	Modality	Intervention-Endline (n)	%	Intervention-Baseline (n)	%	Change1 in %	p-value	Control-Endline (n)	%	Control-Baseline (n)	%	Change2 in %	p-value	Difference between changes1 & 2 in %
Separation	Yes	172	66.2%	179	69.0%	-2.8%	0.033	149	57.1%	159	60.9%	-3.8%	0.038	+1.0%
Composting	Yes	205	78.8%	151	58.1%	+20.7%	<0.001	81	31.0%	117	44.8%	-13.8%	<0.001	+34.5%
Incineration	Yes	28	10.8%	132	50.8%	-40.0%	<0.001	160	61.3%	199	76.2%	-14.9%	<0.001	-25.1%
Storage in Bags	Yes	105	40.4%	73	28.1%	+12.3%	0.619	111	42.5%	105	40.2%	+2.3%	0.657	+10.0%
Evacuation	Yes	260	100.0%	154	59.2%	+40.8%	<0.001	124	47.5%	170	65.1%	-17.6%	<0.001	+58.4%

- *Note.* Change1 = Intervention group change between endline and baseline. Change2 = Control group change between endline and baseline. p-values indicate significance of within- and between-group differences.

Intervention and control groups are compared at baseline and endline. Change1, change from baseline to endline in the intervention group; Change2, change from baseline to endline in the control group. Differences represent the net effect between the two groups.

➢ *Waste Management Practices: Comparative trends and statistical significance:*

In the intervention group, two practices demonstrated the most substantial and statistically significant improvements: Composting increased by +20.7% ($p < 0.001$). Evacuation rose by +40.8% ($p < 0.001$) These shifts diverged markedly from control group trends, indicating strong intervention impact. In contrast, the control group experienced notable declines: composting decreased by −13.8% ($p < 0.001$) and evacuation regressed by −17.6% ($p < 0.001$). Among declining or mixed practices: Incineration dropped sharply in the intervention group (−40.0%, $p < 0.001$).

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Waste separation declined slightly in both groups: Intervention: −2.8% (p = 0.033); Control −3.8% (p = 0.038). For low-significance practices, changes were modest and statistically non-significant: Storage in bags increased: Intervention: +12.3% (p = 0.619) and Control: +2.3% (p = 0.657).

➢ *Analysis by Characteristics*

Table 7 Analysis by Characteristics at Baseline and Endline

Characteristics	% Baseline	% Endline	Variation (%)	Difference Between Subgroups (%)
Age Group				
18–25	25.14%	35.12%	+9.98%	
26–35	29.37%	29.56%	+0.19%	
36–45	21.50%	20.15%	-1.35%	
46–55	14.78%	10.75%	-4.03%	
Over 55	9.21%	4.41%	-4.80%	14.78% (between +9.98% and -4.80%)
Gender of Respondent				
Male	36.47%	36.47%	0.00%	
Female	63.53%	63.53%	0.00%	0.00%
Marital Status				
Single	28.02%	27.64%	-0.38%	
Married	67.37%	67.75%	+0.38%	0.76%
Widowed	1.92%	1.92%	0.00%	
Divorced	2.69%	2.69%	0.00%	
Education Level				
Without education	12.86%	12.28%	-0.58%	
Primary school	12.28%	10.36%	-1.92%	
Secondary school	50.10%	53.17%	+3.07%	
Professional training	1.54%	5.37%	+3.83%	
Bachelor	23.03%	18.62%	-4.41%	8.24% (between +3.83% and -4.41%)
Master	0.19%	0.19%	0.00%	
Religion				
Catholic	34.17%	35.32%	+1.15%	
Protestant	34.93%	33.78%	-1.15%	
Muslim	4.03%	4.61%	+0.58%	
Adventist	11.13%	10.56%	-0.57%	
Revival church	8.45%	9.02%	+0.57%	
Other religion	5.18%	4.61%	-0.57%	
Without religion	2.11%	2.11%	0.00%	2.30% (between +1.15% and -1.15%)

- Note. Percentages are shown for baseline and endline. Variation represents the change from baseline to endline within each subgroup. The last column shows the difference between the highest and lowest subgroup variations.

According to the data presented, the most pronounced demographic shift occurred among youth aged 18–25, whose representation increased by nearly 10 percentage points. In contrast, older adults, particularly those over 55, experienced a notable decline, suggesting a generational shift in engagement or exposure. Gender distribution remained unchanged, indicating no differential participation or impact by sex throughout the study period. Marital status showed minimal variation; the slight shift from single (28.02%) to married (67.75%), with a spread of +0.76%, is negligible and unlikely to hold programmatic significance.

In terms of education, the most dynamic increases were observed in professional training (+3.83%) and secondary education (+3.07%), pointing to greater involvement from vocationally trained and mid-level educated individuals. The decline in bachelor-level participants (−4.41%) may reflect shifting priorities, outreach limitations, or changes in accessibility. Religious affiliation remained relatively stable, though modest shifts—particularly between Catholic (+1.15%) and Protestant (−1.15%), may inform more tailored messaging for faith-based outreach. The overall spread of 2.30% suggests limited but potentially strategic relevance.

➢ *Results Consolidation*

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Table 8. Effect of the Intervention on Waste Management Practices

Waste Practice	Groups	Typhoid Fever (Baseline)	% Baseline	Typhoid Fever (Endline)	% Endline	P-value	Net Change (%)	Difference p-value
Waste separation	Intervention group	36	13.8%	22	8.5%	0.033	-5.3%	
	Control group	35	13.4%	55	21.1%	0.038	+7.7%	0.071
Waste composting	Intervention group	17	6.5%	32	12.3%	<0.001	+5.8%	
	Control group	25	9.6%	29	11.1%	<0.001	+1.5%	0.043
Waste incineration	Intervention group	31	11.9%	11	4.2%	<0.001	-7.7%	
	Control group	31	11.9%	49	18.8%	<0.001	+6.9%	0.085
Storage in bags	Intervention group	84	32.3%	10	3.8%	0.619	-28.5%	
	Control group	59	22.6%	42	16.1%	0.657	-6.5%	0.222
Evacuation	Intervention group	77	29.6%	32	12.3%	<0.001	-17.3%	
	Control group	61	23.4%	41	15.7%	<0.001	-7.7%	0.096

- Note. Intervention group refers to the population that received the intervention, while control group refers to the population that did not receive it. P-values less than .05 indicate statistically significant results.

As impact of Household waste practices on Typhoid Fever prevalence, in the intervention group, both waste incineration (11.9%) and evacuation (29.6%) were associated with statistically significant reductions in typhoid fever prevalence. Waste separation also showed a meaningful decline, while the control group experienced an increase for the same practice, highlighting the protective effect of the intervention. Although storage in bags yielded the largest reduction (−28.5%), this change was not statistically significant ($p = 0.619$). In contrast, waste composting led to increased typhoid prevalence in both groups, with a sharper rise in the intervention group (+5.8%, $p < 0.001$), indicating potential risks linked to unsafe composting practices. Notably, several practices, including waste separation and incineration, were associated with increased typhoid prevalence in the control group.

Table 9 Effect of Typhoid Fever Prevalence Comparison by Group (Intervention Group vs Control Group)

Group	Yes (Baseline)	% Baseline	Yes (Endline)	% Endline	Net Change (%)	p-value
Intervention Group	114	43.8%	33	12.7%	−31.1%	0.033
Control Group	100	38.3%	77	29.5%	−8.8%	<0.001
Total	214	41.1%	110	21.1%	−20.0%	<0.001

- Note: The table presents the comparison of typhoid fever prevalence between the intervention and control groups at baseline and endline. P-values less than .05 indicate statistically significant differences.

Effectiveness of the Intervention: The intervention group experienced a substantial decline in typhoid fever prevalence, dropping from 43.8% at baseline to 12.7% at endline, a net reduction of 31.1% points. This change is statistically significant ($p = 0.033$), indicating a meaningful impact attributable to the intervention. The control group also showed a statistically significant reduction, from 38.3% to 29.5% ($p < 0.001$), but the net change of 8.8% points was markedly smaller than that observed in the intervention group. Across both groups, the overall prevalence decreased by 20.0% points, confirming that change occurred during the study period. However, the intervention group accounted for the majority of this shift, underscoring the effectiveness of the targeted intervention.

IV. DISCUSSION

A. *Description of Endline (Intervention vs Control Groups)*

➢ *Table 1. Distribution of Waste Management Practices and Age of the Respondents in the Endline*

- *Adoption of Waste Management Practices*

✓ *Composting and Evacuation:*

In the intervention group, composting (78.8%) and evacuation (100%) were the most widely adopted practices, both with strong statistical significance ($p < 0.001$). This indicates that targeted interventions can significantly shift

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household behaviour toward environmentally sustainable practices. Recent evidence from UNEP, (2024) emphasises composting and organised evacuation as critical strategies for reducing landfill dependency and advancing circular economy goals.

✓ *Incineration:*

A sharp contrast was observed: only 10.8% of households in the intervention group used incineration compared to 61.3% in the control group. This suggests that awareness campaigns and training discouraged harmful practices. Studies in Sub-Saharan Africa confirm that uncontrolled incineration contributes to greenhouse gas emissions and health risks, underscoring the need for alternatives (Okorondu *et al*., 2024).

✓ *Waste Separation:*

Moderate adoption was recorded (66.2% intervention vs. 57.1% control), both statistically significant. This reflects growing awareness but also highlights challenges in infrastructure and enforcement. A systematic review of citizen attitudes found that separation practices often depend on municipal support and incentives (Konstantinidou *et al.*, 2024), .

✓ *Storage in Bags:*

Adoption remained marginal (40–42%), with no significant differences between groups. This suggests that storage alone is not perceived as a sustainable solution without complementary evacuation or recycling systems (Omondi *et al*., 2024).

- *Age-Based Adoption Patterns*

✓ *Older Household Heads (Over 55):*

In both groups, older respondents showed the highest adoption rates of promoted practices. For example, composting peaked at 90.9% in the intervention group and separation at 66.7% in the control group. This may reflect stronger traditional knowledge and responsibility toward household management. UNEP, (2024) notes that younger populations often engage more in recycling and innovation, while older groups maintain consistency in traditional practices.

✓ *Younger Respondents (18–25):*

Showed strong engagement in composting (63%) and evacuation (55.6%) in the control group, suggesting openness to new practices when supported by training. However, variability in middle-aged groups (26–45) indicates competing priorities and lower consistency (Höflinger *et al*., 2020).

- *Implications*

✓ *Policy and Program Design:*

The findings highlight the need for age-sensitive interventions**.** Older household heads can be leveraged as community champions, while younger groups may benefit from digital awareness campaigns and incentives.

✓ *Sustainability Goals:*

Promoting composting and organized evacuation aligns with the UN's circular economy agenda and climate adaptation strategies.

✓ *Challenges:*

Persistent reliance on incineration in control groups underscores the need for stronger regulatory frameworks and accessible alternatives.

➢ *Table 2. Distribution of Waste Management Practices and Gender of the Respondents in Endline*

The findings presented in Table 2 reveal notable differences in waste management practices between the intervention and control groups, as well as variations by gender. Overall, the intervention group demonstrates significantly higher adoption of improved waste management practices compared to the control group, suggesting that the intervention was effective in promoting environmentally responsible behaviours.

One of the most striking results is the universal adoption of waste evacuation among both male and female respondents in the intervention group (100% for both genders), with a highly significant statistical difference ($p < 0.001$). This contrasts sharply with the control group, where only 39.8% of males and 52.1% of females reported practicing waste evacuation. The high uptake in the intervention group may indicate that the program strongly emphasized proper waste disposal systems or facilitated access to waste evacuation services. Similar findings have been reported in community-based environmental interventions where awareness campaigns and training significantly improved waste disposal practices (UNEP, 2021; World Bank, 2018).

Waste composting also shows a substantial difference between the intervention and control groups. In the intervention group, composting was adopted by 75.0% of males and 81.0% of females, compared to only 27.6% of males and 33.1% of females in the control group. The statistically significant p-values (<0.001) indicate that the intervention likely contributed to increasing awareness and capacity for organic waste recycling. Composting is widely recognized as an effective strategy for reducing household waste while improving soil fertility, especially in urban and peri-urban settings (Kabasiita *et al*., 2022).

Waste separation was moderately practiced in both groups but still showed higher adoption in the intervention group. Among females, 67.9% practiced separation compared with 56.4% in the control group, while among males the rates were 63.0% and 58.2% respectively. The statistical significance among males ($p = 0.033$) suggests that the intervention had a measurable influence on promoting sorting behaviours. Waste segregation at source is a critical step in sustainable waste management because it facilitates recycling, composting, and safe disposal of waste streams.

In contrast, waste incineration was relatively uncommon in the intervention group, with only 9.8% of males and 11.3% of females reporting its use. However,

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incineration was the most commonly reported practice in the control group, particularly among females (65.0%) and males (55.1%). This pattern suggests that in the absence of structured waste management interventions, households tend to rely on burning waste as a disposal method. While incineration may reduce waste volume, uncontrolled burning can produce harmful pollutants and pose health risks, especially in densely populated communities (United Nations Environment Programme, 2020).

The practice of storing waste in bags shows moderate adoption in both groups and appears to be the least influenced by the intervention. In the intervention group, 51.1% of males and 34.5% of females reported storing waste in bags, whereas in the control group the rates were 35.7% for males and 46.6% for females. The non-significant p-values ($p = 0.619$ and $p = 0.657$) indicate that this practice may already be common regardless of the intervention or may depend more on household convenience and availability of materials rather than behavioural change.

Gender differences also emerge from the results. Female respondents consistently demonstrate higher participation in several key practices, particularly composting and waste separation. This trend likely reflects the central role women often play in household environmental management, including waste handling and sanitation activities. Similar gender dynamics in household waste management have been documented in several studies across developing countries, where women are often the primary managers of domestic waste (UN Women, 2025).

Overall, the results highlight the effectiveness of the intervention in promoting sustainable waste management practices such as composting, separation, and proper evacuation, while reducing reliance on environmentally harmful practices like uncontrolled waste burning. The strong participation of female respondents also underscores the importance of integrating gender-responsive strategies in environmental programs to maximize community-level impact (UNEP, 2021; Iverson *et al*., 2018).

- *Table 3 Distribution of Waste Management Practices and Marital Status of the Respondents in Endline*

The results reveal clear differences in the adoption of waste management practices according to marital status between the intervention and control groups at the endline evaluation. Overall, respondents in the intervention group showed higher engagement in sustainable waste management practices such as composting, waste separation, and organized waste evacuation. This suggests that the intervention significantly improved environmental awareness and promoted responsible household waste management behaviours, consistent with findings from studies on community-based environmental programs (UNEP, 2021; Iverson *et al*., 2018).

Composting was the most widely adopted practice in the intervention group across marital categories, particularly among widowed (100%), divorced (85.7%), and married respondents (79.1%). Single respondents also showed high adoption (76.1%). This indicates that the intervention effectively promoted organic waste recycling and compost production, which contributes to waste reduction and improved soil fertility (Diacono *et al*., 2022).

Waste separation was also widely practiced, especially among single respondents (76.1%) and married respondents (62.7%), reflecting improved awareness of waste sorting at the household level. In contrast, waste incineration was relatively rare in the intervention group but remained the most common disposal method in the control group, particularly among single and married respondents. This suggests that households without structured waste management interventions often rely on burning waste, despite its environmental and health risks (UNEP, 2021).

According to World Bank (2022), waste storage in bags showed moderate adoption in both groups and appeared less influenced by the intervention, likely because it is a common household practice determined by convenience and material availability. A key finding was the universal adoption of waste evacuation in the intervention group (100% across all marital categories), compared with lower rates in the control group. This indicates that the intervention likely improved access to organized waste collection and encouraged proper waste disposal.

Overall, the findings demonstrate that the intervention effectively promoted sustainable waste management practices and reduced reliance on environmentally harmful methods such as uncontrolled waste burning. These results highlight the importance of community-based environmental programs and awareness campaigns in improving household waste management and supporting sustainable environmental health (Buntaine, 2024).

- *Table 4. Distribution of Waste Management Practices and Education Level of the Respondents in Endline*

The findings presented in Table 4 highlight important variations in the adoption of waste management practices according to education level between the intervention and control groups at endline. Overall, the intervention appears to have significantly influenced the uptake of environmentally sustainable practices, particularly composting, waste separation, and organized evacuation, across nearly all education categories.

In the intervention group, *waste evacuation* stands out as the most universally adopted practice, with 100% uptake across all education levels and strong statistical significance ($p < 0.001$). This suggests that the intervention successfully promoted structured waste disposal systems regardless of respondents' educational background. Similar findings have been reported in recent studies, which indicate that community-based interventions and infrastructure support can substantially increase participation in organized waste collection systems, even among populations with limited formal education (Lisa *et al*., 2018; UNEP, 2024b).

Waste composting also shows remarkably high adoption rates in the intervention group, particularly among

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respondents with no education (90.0%), primary education (86.7%), and professional training (100%), all with highly significant p-values ($p < 0.001$). This contrasts sharply with the control group, where composting remains low across all education levels (20.8%–33.3%). These results suggest that the intervention effectively addressed knowledge and behavioral barriers associated with organic waste management. This aligns with recent literature emphasizing that targeted environmental education and practical demonstrations can significantly enhance composting practices at the household level (Sun *et al*., 2023; Ferronato *et al*., 2019).

Regarding waste separation, the intervention group again demonstrates higher engagement compared to the control group, especially among respondents without education and those with primary education (both at 80.0%). Although statistical significance varies across education levels, the overall trend indicates improved sorting behaviour due to the intervention. In contrast, the control group shows moderate adoption, with the highest rate among Bachelor-level respondents (63.6%). These findings support previous research indicating that waste segregation is strongly influenced by awareness campaigns and access to appropriate facilities rather than education level alone (Maas *et al*., 2013; UNEP, 2024b).

Conversely, waste incineration, which is generally considered an environmentally harmful practice when uncontrolled, is significantly reduced in the intervention group across most education levels ($p < 0.001$). Adoption rates remain low (10.0%–25.0%), except for the Master's category, where the 100% value is based on a single respondent and is not statistically meaningful. In the control group, however, incineration is the most prevalent practice, with high adoption rates across all education levels (57.6%–70.8%) and strong statistical significance. This suggests that, in the absence of intervention, households tend to rely on convenient but environmentally unsafe disposal methods. These findings are consistent with studies showing that open burning of waste remains common in low-resource settings due to lack of alternatives (Wiedinmyer *et al*., 2014; World Bank, 2022).

The practice of storage in bags shows mixed results. In the intervention group, it is most prominent among Bachelor-level respondents (67.7%, $p < 0.001$), while adoption is relatively low among other education levels. In the control group, moderate adoption is observed, particularly among respondents with professional training (55.0%). This suggests that storage practices may be influenced more by convenience and household logistics than by the intervention itself, a trend also noted in previous studies (Ferronato *et al*., 2019).

Interestingly, respondents without formal education in the intervention group demonstrate high engagement in key sustainable practices such as composting (90%) and waste separation (80%). This finding challenges the common assumption that higher education is always associated with better environmental behaviour. Instead, it underscores the effectiveness of inclusive, community-based interventions that rely on practical training and social mobilization rather than formal education alone (Lisa *et al*., 2018; UNEP, 2024b).

In contrast, the control group shows a pattern where less sustainable practices dominate, particularly incineration, while environmentally friendly practices such as composting and separation remain limited. This disparity between the two groups clearly demonstrates the positive impact of the intervention in promoting sustainable waste management behaviours.

Overall, the results confirm that the intervention significantly improved the adoption of sustainable waste management practices across all education levels while reducing reliance on harmful methods such as waste incineration. These findings highlight the importance of community-driven environmental education, practical training, and accessible waste management systems in influencing behavior change. Importantly, the impact of the intervention appears to transcend educational disparities, suggesting that well-designed programs can effectively reach and benefit diverse population groups.

- *Table 5. Distribution of Waste Management Practices and Religion of the Respondents in Endline*

The findings presented in Table 5 demonstrate significant differences in the adoption of waste management practices according to religious affiliation between the intervention and control groups at endline. Overall, the intervention appears to have positively influenced environmentally sustainable practices such as waste separation, composting, and organized waste evacuation, while reducing reliance on less sustainable methods like open waste incineration. These results align with existing literature emphasizing the effectiveness of community-based environmental interventions in improving household waste management behaviors in developing countries (Maas *et al*., 2013).

In the intervention group, evacuation and composting emerged as the most widely adopted practices across all religious categories, with evacuation reaching universal adoption (100%) and showing strong statistical significance ($p < 0.001$). This high level of participation suggests that the intervention successfully promoted organized waste collection systems and improved awareness of proper disposal methods. Similar findings have been reported by Ferronato *et al*., (2019), who highlight that structured waste collection and community engagement are key drivers of improved waste management in low- and middle-income settings.

Composting also recorded high adoption rates, particularly among Muslims (87.5%), Protestants (82.7%), and Catholics (76.1%), with statistically significant variation across religious groups ($p < 0.001$). This suggests that religious affiliation may influence environmental behaviour, possibly through value systems that promote stewardship of the environment. The high uptake of composting in the intervention group reflects increased awareness of organic

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waste valorisation and its benefits for soil fertility and sustainable agriculture, consistent with findings by Varol *et al.*, (2021), who emphasize composting as a key strategy for sustainable organic waste management.

Waste separation also showed strong adoption in the intervention group, particularly among other church members (72.7%), Muslims (68.8%), and Catholics (68.2%), with significant differences across religious groups ($p = 0.041$). This indicates that the intervention effectively promoted sorting behaviours at the household level, which is essential for efficient recycling and waste recovery systems. According to Wiedinmyer *et al*., (2014), improved waste segregation can significantly reduce environmental pollution by minimising open burning and enhancing material recovery.

In contrast, waste incineration remained relatively low in the intervention group, with most religious categories reporting rates below 12%, although variation was statistically significant ($p < 0.001$). This decline suggests a shift away from harmful disposal practices, likely due to increased awareness of the health and environmental risks associated with open waste burning. Studies have shown that such practices contribute significantly to air pollution and greenhouse gas emissions, particularly in developing (Wiedinmyer *et al*., 2014).

Storage of waste in bags showed moderate adoption across both groups and was not statistically significant ($p = 0.619$), indicating that this practice may be influenced more by convenience and household conditions than by the intervention itself. This finding is consistent with previous research suggesting that certain routine waste handling practices are less responsive to behavioural change interventions (Ferronato *et al*., 2019).

In the control group, less sustainable practices such as waste incineration were more prevalent, with relatively high adoption across all religious categories (ranging from 50% to 63.2%), and significant variation ($p < 0.001$). This highlights the absence of effective intervention measures and underscores the continued reliance on environmentally harmful disposal methods. Similar patterns have been documented in urban areas of developing countries, where inadequate waste management systems often lead households to resort to open burning (Maas *et al*., 2013).

Waste separation and evacuation in the control group showed moderate adoption, with significant differences across religious groups ($p = 0.048$ and $p < 0.001$, respectively), but remained lower compared to the intervention group. Composting was the least adopted practice, with generally low rates across all religious affiliations, further emphasizing the limited awareness and promotion of sustainable waste management practices in the absence of targeted interventions.

Overall, the results demonstrate that the intervention significantly improved the adoption of environmentally friendly waste management practices across different religious groups. The observed variations by religion suggest that cultural and social factors may influence the uptake of such practices, and future programs could benefit from integrating faith-based approaches to enhance community participation. These findings reinforce the importance of education, awareness campaigns, and community engagement in promoting sustainable waste management and reducing environmental and public health risks in developing countries.

B. *Waste Management Practices — Baseline vs Endline*

- *Table 6. Waste Management Practices — Baseline vs Endline*

The findings presented in Table 6 highlight substantial differences in the evolution of household waste management practices between the intervention and control groups from baseline to endline, suggesting a strong positive effect of the intervention on environmentally sustainable behaviours.

One of the most notable outcomes is the significant increase in composting practices within the intervention group (+20.7%, $p < 0.001$), contrasted with a marked decline in the control group (−13.8 %, $p < 0.001$). This divergence indicates that the intervention effectively promoted organic waste valorisation. Composting is widely recognized as a key strategy for sustainable waste management, particularly in low- and middle-income settings where organic waste constitutes a large proportion of household waste streams (Varol *et al*., 2021). The observed improvement suggests increased awareness and adoption of environmentally friendly techniques among beneficiaries.

Similarly, waste evacuation practices showed the largest improvement in the intervention group (+40.8%, $p < 0.001$), while the control group experienced a significant decline (−17.6%, $p < 0.001$), resulting in a substantial net effect (+58.4%). This finding reflects improved access to or utilisation of organized waste collection systems, which are critical for reducing environmental contamination and public health risks (Kaza *et al.*, 2018). The strong contrast between groups underscores the effectiveness of the intervention in facilitating better waste disposal behaviours.

In contrast, waste incineration, a practice often associated with environmental and health hazards, declined sharply in both groups, though more substantially in the intervention group (−40.0% vs. −14.9%, $p < 0.001$). This suggests that the intervention contributed to discouraging unsafe waste disposal methods, aligning with global recommendations to minimise open burning due to its contribution to air pollution and greenhouse gas emissions (Wiedinmyer *et al.*, 2014).

Waste separation practices showed a slight but statistically significant decline in both groups (intervention: −2.8%, control: −3.8%). Although the decreases are relatively small, they may indicate persistent structural or behavioural barriers, such as lack of adequate infrastructure or incentives for sorting waste at the household level. Previous studies have shown that sustained waste separation requires continuous

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awareness, availability of sorting facilities, and supportive policy frameworks (Adefris *et al*., 2023).

Storage of waste in bags increased modestly in both groups, but these changes were not statistically significant. This suggests that the practice is likely influenced more by convenience and existing household habits than by the intervention itself. Similar findings have been reported in other studies where basic storage practices remain relatively stable unless directly targeted by behavioural interventions (Apio *et al*., 2024).

Overall, the results demonstrate that the intervention was particularly effective in promoting high-impact, sustainable practices such as composting and organized waste evacuation, while reducing reliance on harmful methods like incineration. These outcomes reinforce the importance of community-based environmental programs and targeted awareness campaigns in driving behavioural change. However, the limited progress in waste separation highlights the need for complementary structural support, including infrastructure development and policy enforcement, to achieve comprehensive improvements in waste management systems (Istiqomah *et al*., 2024).

C. *Analysis by Characteristics*

- *Table 7. Analysis by Characteristics at Baseline and Endline*

The findings in Table 7 provide important insights into the study population's demographic dynamics between baseline and endline, highlighting how different socio-demographic characteristics may have influenced participation and engagement with the intervention.

One of the most notable changes is in the age distribution: the proportion of respondents aged 18–25 increased by 9.98%, while older age groups, particularly those above 55 years, declined by 4.80%. This pattern suggests a growing engagement of younger individuals in the intervention or study activities, possibly reflecting higher receptiveness to environmental awareness campaigns and behavioural change initiatives among youth. Previous studies have shown that younger populations are generally more responsive to sustainability-oriented interventions due to greater exposure to education, media, and innovation-driven messaging (Rees *et al*., 2018; Tabanao *et al*., 2025). Conversely, lower participation among older adults may indicate barriers such as resistance to change, limited access to information, or entrenched behavioural patterns.

Gender distribution remained completely stable across baseline and endline, with no variation observed. This indicates that the intervention neither disproportionately attracted nor excluded participants based on sex, suggesting equitable reach and inclusivity. Such balance is important, as gender-inclusive approaches are considered essential for the success of community-based environmental programs (UNEP, 2022).

Marital status showed only minimal variation (+0.76% difference between subgroups), indicating that household composition remained largely unchanged throughout the study period. This stability suggests that marital status did not play a significant role in influencing participation or behavioural outcomes in this context. Similar findings have been reported in studies where socio-demographic stability allows for clearer attribution of observed changes to the intervention rather than to population shifts (Kaza *et al.*, 2018).

In terms of education level, moderate but meaningful shifts were observed. Participation increased among individuals with secondary education (+3.07%) and professional training (+3.83%), while it declined among those with bachelor-level education (−4.41%). This may indicate that the intervention was particularly effective in reaching middle-level and vocationally trained individuals, who often play a central role in implementing practical environmental practices at the household level. The decline among higher-educated participants could reflect competing commitments or lower perceived relevance of the intervention. Evidence suggests that education influences environmental behaviour, but practical engagement is often stronger among individuals with applied or vocational skills when interventions are action-oriented (Adu-Boahen et al., 2021; Ifegbesan et al., 2022).

Religious affiliation remained relatively stable, with only minor variations across groups (maximum spread of 2.30%). However, small shifts between major groups, such as Catholics (+1.15%) and Protestants (−1.15%), may still hold strategic importance for community engagement. Faith-based organizations are known to play a significant role in shaping environmental attitudes and mobilizing collective action, particularly in community-based programs (Sayuti *et al.*, 2025; Office *et al*., 2024). Therefore, even modest variations could inform more targeted and culturally sensitive communication strategies.

Overall, the limited variation across most socio-demographic characteristics suggests that the study population remained relatively stable over time, strengthening the internal validity of the findings. At the same time, the notable increase in youth participation and shifts in education levels highlight the importance of tailoring interventions to specific demographic groups. These results reinforce the need for inclusive, context-sensitive approaches that consider age, education, and social structures to enhance the effectiveness and sustainability of environmental interventions (Brown, 2024).

D. *Results Consolidation*

- *Table 8. Effect of the Intervention on Waste Management Practices*

The findings presented in Table 8 provide important evidence on the relationship between household waste management practices and the prevalence of Typhoid Fever, highlighting the differential impact of the intervention compared to the control group. Overall, the results suggest

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that the intervention contributed to reducing disease risk through improved waste management behaviours, although some practices revealed mixed or unintended effects.

Waste separation in the intervention group was associated with a decline in typhoid fever prevalence (−5.3%, $p = 0.033$), while the control group experienced an increase (+7.7%, $p = 0.038$). Although the difference between groups was not statistically significant ($p = 0.071$), the contrasting trends suggest a protective effect of the intervention. Proper waste separation reduces environmental contamination and limits exposure to disease vectors such as flies, which are known to transmit pathogens responsible for typhoid and other enteric infections. Similar findings have been reported in recent studies emphasizing the role of improved waste handling in reducing infectious disease risks (WHO, 2023a).

Waste composting showed a statistically significant increase in typhoid prevalence in both groups, with a more pronounced rise in the intervention group (+5.8%, $p < 0.001$). This finding may indicate that composting, when not properly managed, can create favourable conditions for pathogen survival and vector breeding. Inadequate composting techniques—such as poor aeration, insufficient temperature control, or proximity to living spaces—can increase exposure to harmful microorganisms. Recent evidence highlights that while composting is environmentally beneficial, unsafe practices may pose public health risks, particularly in low-resource settings (Woime, 2025).

Waste incineration demonstrated a strong and statistically significant reduction in typhoid fever prevalence in the intervention group (−7.7%, $p < 0.001$), whereas the control group showed an increase (+6.9%, $p < 0.001$). Although the between-group difference was not statistically significant ($p = 0.085$), the opposing trends suggest that controlled or reduced reliance on unsafe disposal methods contributed to better health outcomes. While open burning is generally discouraged due to air pollution risks, its reduction or safer management may help limit pathogen exposure from accumulated waste (Ferronato *et al*., 2019).

Storage of waste in bags resulted in the largest observed reduction in typhoid prevalence in the intervention group (−28.5%), although this change was not statistically significant ($p = 0.619$). This suggests that while improved containment of waste may reduce exposure pathways, the variability of the data limits definitive conclusions. Nonetheless, proper storage is recognized as an important barrier against vectors and environmental contamination, especially when combined with regular waste collection services (Apio *et al*., 2024).

Waste evacuation practices were also associated with a significant reduction in typhoid fever prevalence in the intervention group (−17.3%, $p < 0.001$), compared to a smaller decline in the control group (−7.7%, $p < 0.001$). Although the difference between groups was not statistically significant ($p = 0.096$), the larger reduction in the intervention group underscores the importance of organized waste removal systems in minimising health risks. Efficient waste evacuation reduces the accumulation of waste in residential areas, thereby limiting breeding grounds for disease vectors and reducing exposure to contaminated environments (World Bank, 2026).

Overall, the results demonstrate that the intervention contributed to improved health outcomes by promoting safer waste management practices, particularly in reducing exposure to factors associated with Typhoid Fever transmission. However, the increase in disease prevalence associated with composting highlights the need for proper technical guidance and monitoring when promoting environmentally sustainable practices. These findings reinforce the importance of integrating public health considerations into waste management interventions, ensuring that behavioral change is accompanied by adequate knowledge, infrastructure, and supervision. Community-based programs should therefore combine environmental education with practical training and supportive systems to achieve both environmental sustainability and health protection (Kim *et al.*, 2023).

➢ *Table 9. Effect of Typhoid Fever Prevalence Comparison by Group (Intervention Group vs Control Group)*

The findings from Table 9 reveal a substantial reduction in typhoid fever prevalence in the intervention group, dropping from 43.8% at baseline to 12.7% at endline, a net decline of 31.1 percentage points (p = 0.033). In contrast, the control group showed a smaller but statistically significant reduction, from 38.3% to 29.5% (−8.8 percentage points, p < 0.001). Overall prevalence across both groups decreased by 20.0%, but the intervention group accounted for the majority of this improvement, underscoring the effectiveness of the targeted waste management intervention (World Bank, 2022).

- *Intervention Effectiveness:*

The sharp decline in typhoid prevalence in the intervention group suggests that improved waste management practices, particularly composting with technical oversight, proper evacuation, and reduced incineration, contributed to lowering exposure to contaminated environments (Onuegbu, 2024; World Bank, 2022).

- *Control Group Decline:*

The smaller reduction in the control group may reflect broader community-level improvements or seasonal variations, but the difference in magnitude highlights the added value of structured interventions (Kim *et al.*, 2023).

- *Public Health Link:*

The results confirm that unsafe waste handling is a major driver of enteric infections such as typhoid fever, and interventions that integrate environmental and health considerations can yield measurable health benefits (World Bank, 2022; UNEP, 2024a).

The intervention clearly demonstrates that safer waste management practices can lead to improved health outcomes, particularly in reducing typhoid fever prevalence. However, the findings also highlight the importance of technical

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monitoring and community education to prevent unintended risks from practices like composting (Onuegbu, 2024). Sustainable waste management programs must therefore integrate public health safeguards, infrastructure support, and behavioural change strategies to achieve both environmental sustainability and health protection (World Bank, 2022; Kim *et al.*, 2023).

V. CONCLUSION

This study provides strong evidence that innovative co-created household waste management practices can significantly reduce the burden of typhoid fever in urban, resource-constrained settings such as Goma, North Kivu. The findings demonstrate that the intervention led to substantial improvements in the adoption of sustainable waste management practices, particularly composting, waste separation, and organised waste evacuation, while markedly reducing reliance on unsafe methods such as uncontrolled incineration. These behavioural changes translated into meaningful public health outcomes, with typhoid fever prevalence in the intervention group declining sharply from 43.8% at baseline to 12.7% at endline, a reduction far greater than that observed in the control group (Tadesse *et al*., 2023).

The results highlight the critical link between environmental sanitation and infectious disease control. Improved waste handling practices, especially organised evacuation, reduced exposure to accumulated waste, and better waste containment, played a key role in limiting transmission pathways of typhoid fever. At the same time, the study underscores that not all environmentally friendly practices automatically yield positive health outcomes. The observed increase in typhoid prevalence associated with composting indicates that, when poorly managed, such practices may introduce unintended health risks, emphasising the need for proper technical guidance, monitoring, and safe implementation (Kitole *et al*., 2024; Sisay *et al.*, 2024).

Importantly, the intervention proved effective across diverse socio-demographic groups, demonstrating that community-based, participatory approaches can overcome barriers related to education, gender, and social background. The relative stability of the study population further strengthens the validity of these findings and supports attribution of observed changes to the intervention itself (Aiga *et al*., 2024).

Overall, this study reinforces the value of integrating environmental management with public health strategies. Sustainable waste management interventions should not only promote behavioural change but also ensure access to infrastructure, continuous community engagement, and health-focused education. Policymakers and practitioners should prioritise co-created, context-sensitive approaches that combine environmental sustainability with disease prevention. By doing so, such interventions can significantly reduce enteric diseases such as typhoid fever while advancing broader goals related to urban health and sustainable development (Thalia, 2024; Okin *et al*., 2024).

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